EE4730TU High Frequency Wireless Architectures

Project: Material Characterization using a Time Domain System

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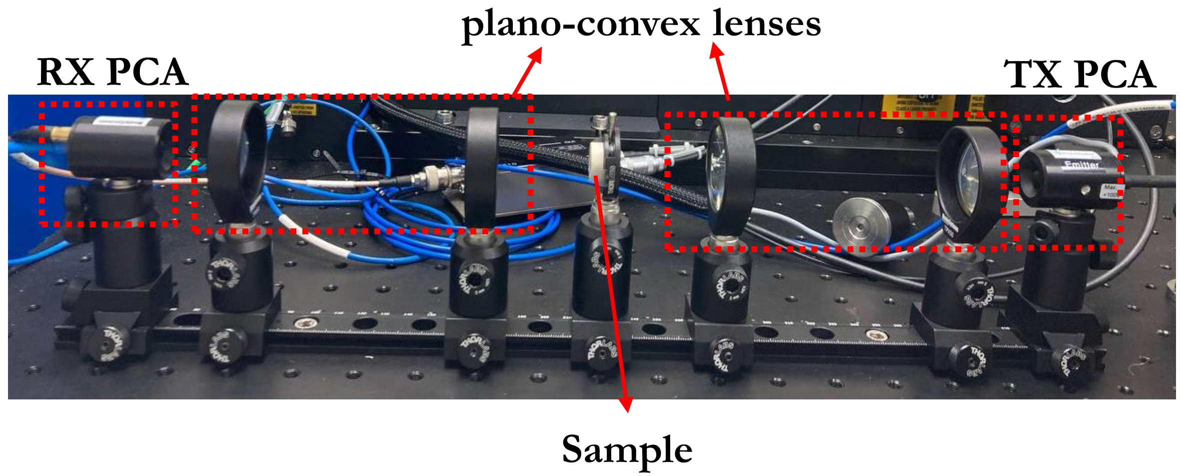
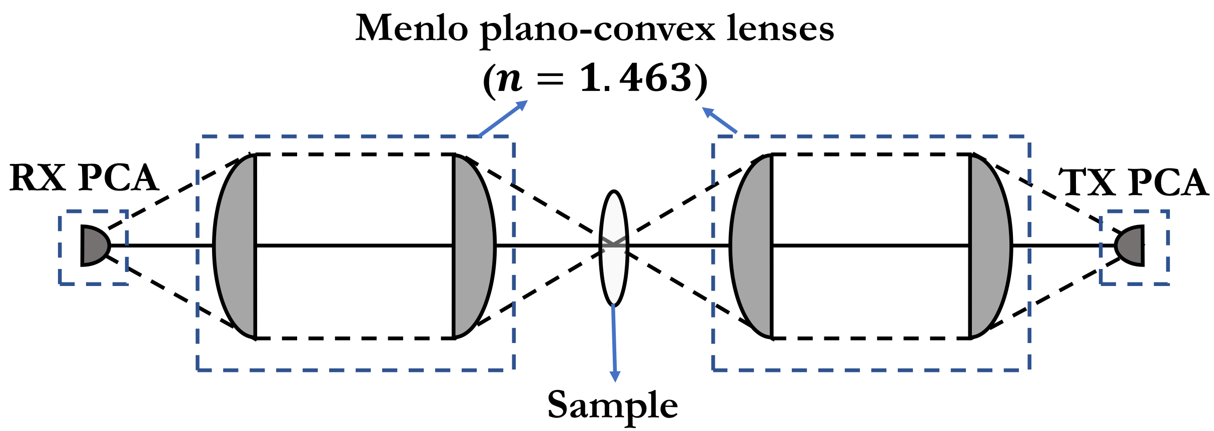
Experiment #1 – Material Characterization with a TD System

Menlo Tera K15

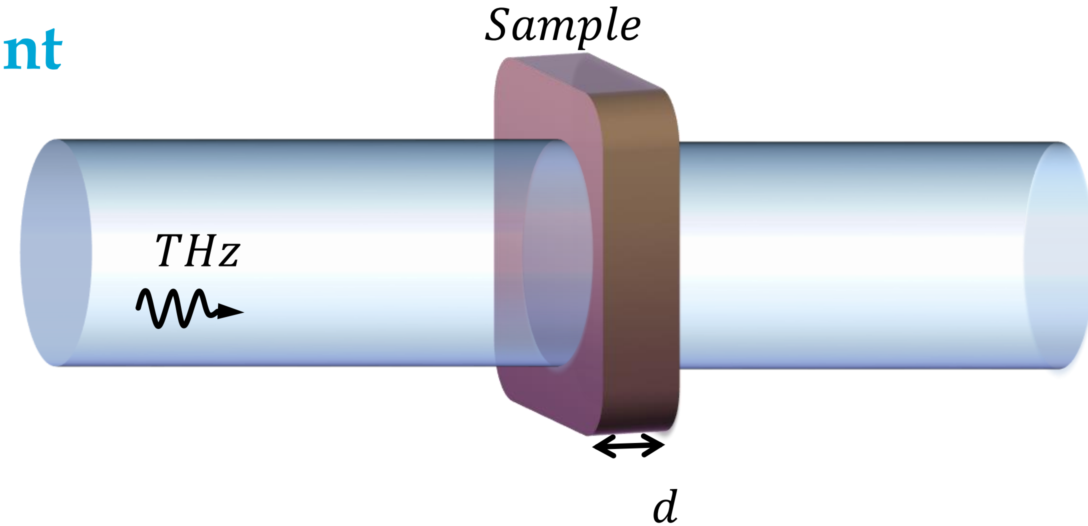




Objective:

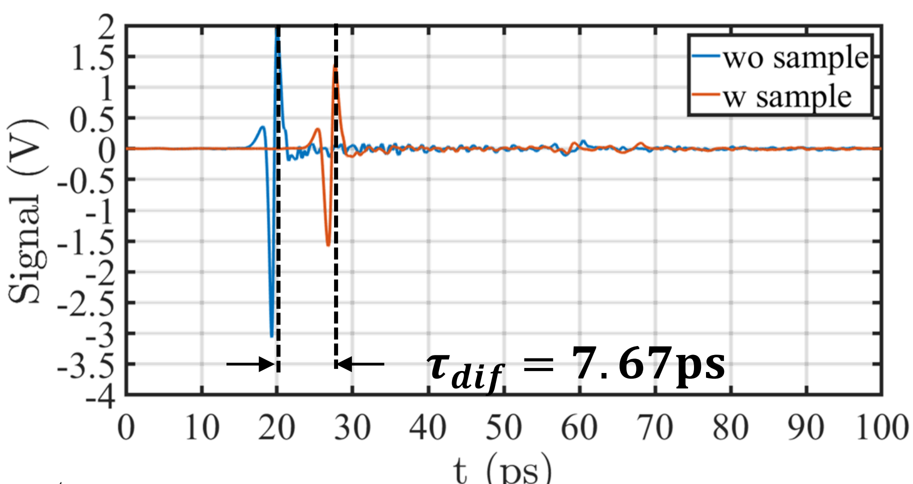
- Understand the manipulation of TD equipment and calibration procedures
- Analyse the material characterization capabilities of the TD system.
- Apply transmission line models to extract the permittivity ε_r, the attenuation in dB/lambda and loss tangent $tan\delta$ of different materials:
  - Silicon, Quartz, PREMIX…

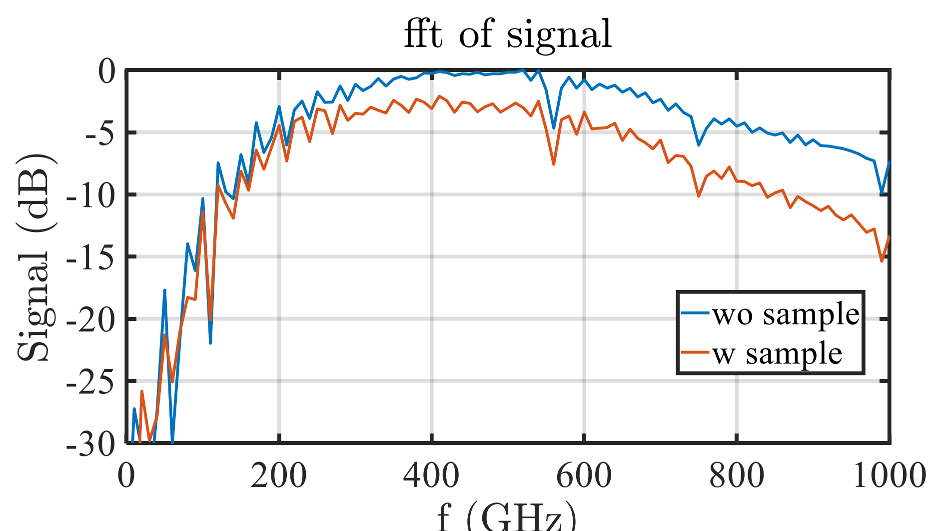
Measurement



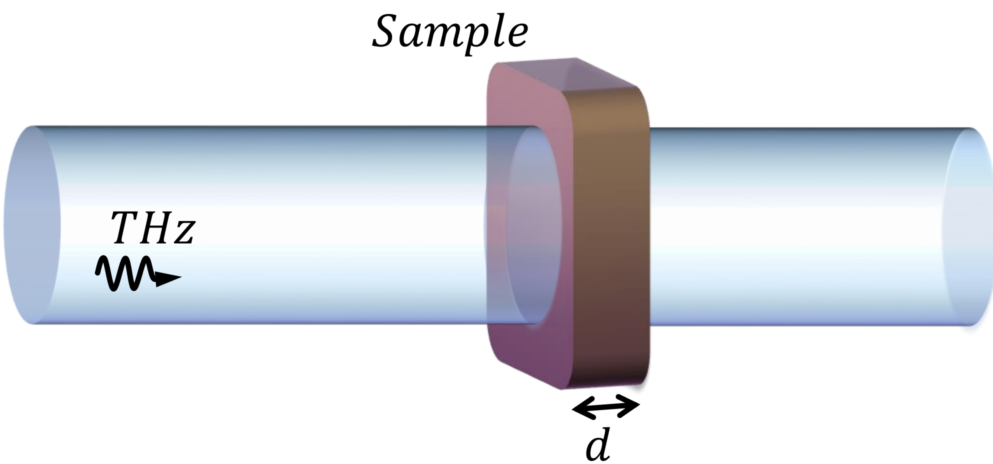
In the laboratory you will perform a differential measurement:

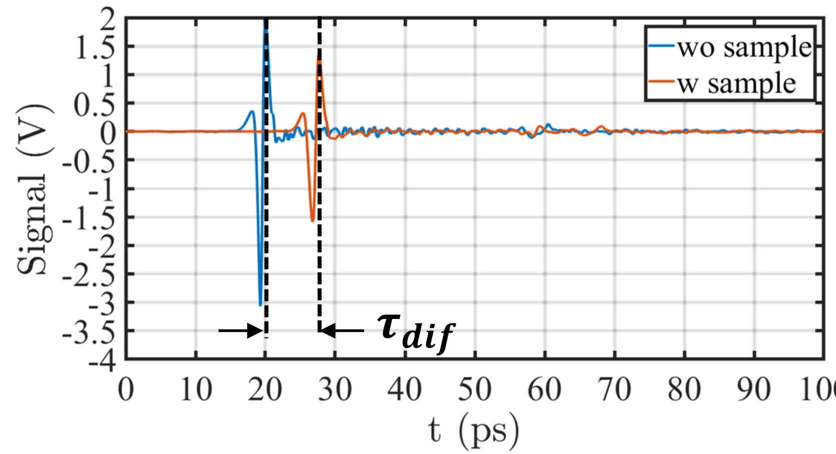
1. Measure the time response without sample
2. Measure the time response with the sample





Obtaining the permittivity





The permittivity can be extracted from the time delay between the two pulse measurements:

$$\tau_{dif} = \tau_d - \tau_0$$

τ_d: time it takes for the pulse to go through the sample

τ_0: time it takes for the pulse to go through air over the thickness of the sample

Knowing that $\tau_0 = \frac{d}{c_0}$ and $\tau_d = \frac{d\sqrt{\varepsilon_r}}{c_0}$

$$\varepsilon_r = \left(\frac{c_0 \tau_d}{d}\right)^2 = \left(\frac{c_0(\tau_{dif} + \tau_0)}{d}\right)^2$$

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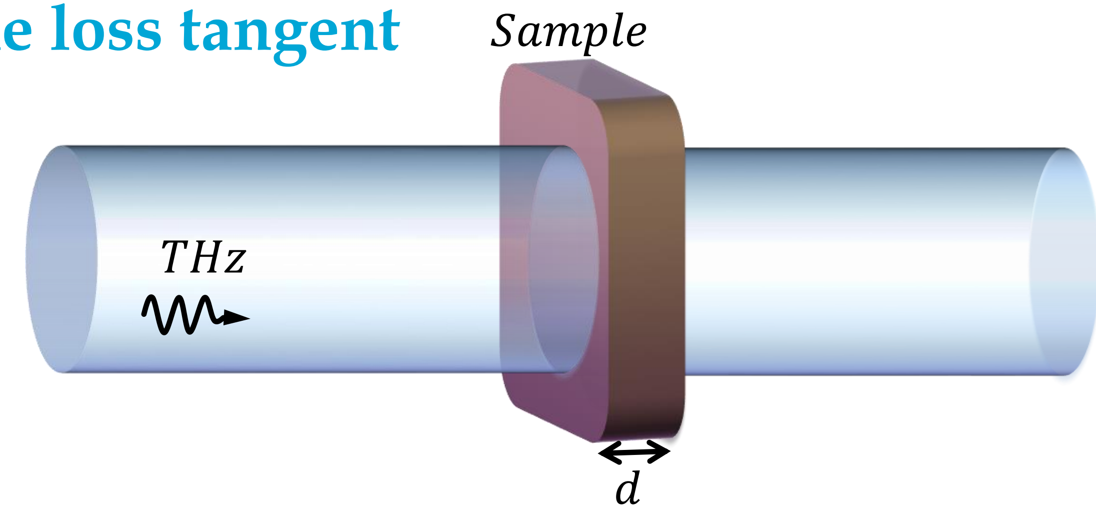
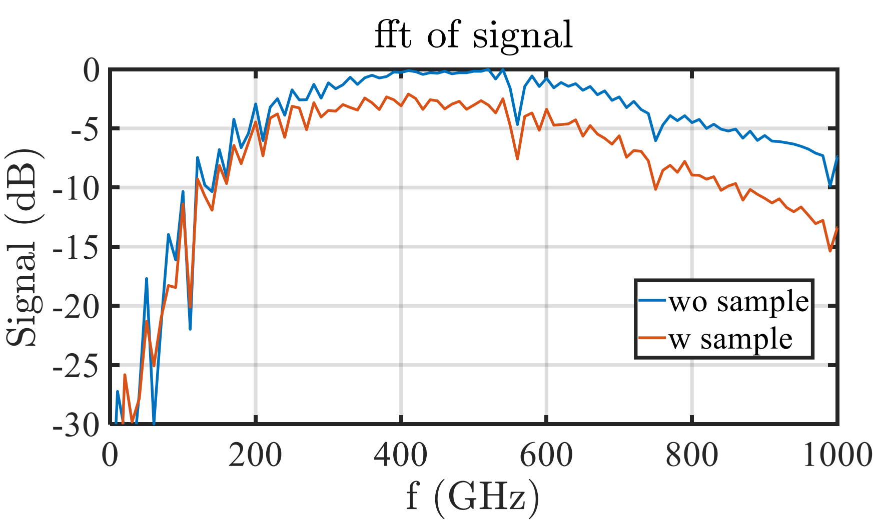
Obtaining the loss tangent



Processing:

1. Convert your signals from the time domain to the frequency domain $S_{21}^{sample}(f)$, $S_{21}^{ref}(f)$
2. Obtained the difference between the two responses
3. Find the permittivity and loss tangent in you transmission line model that fit the measured data

$$\frac{S_{21}^{sample}(f)}{S_{21}^{ref}(f)} \sim \frac{V_{out}^{+}(f)}{V_{in}^{+}(f)}$$



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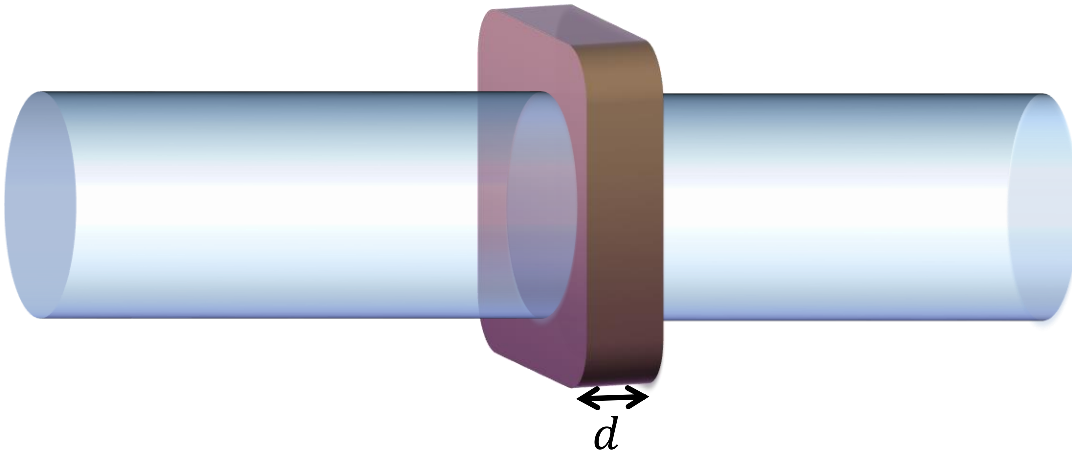
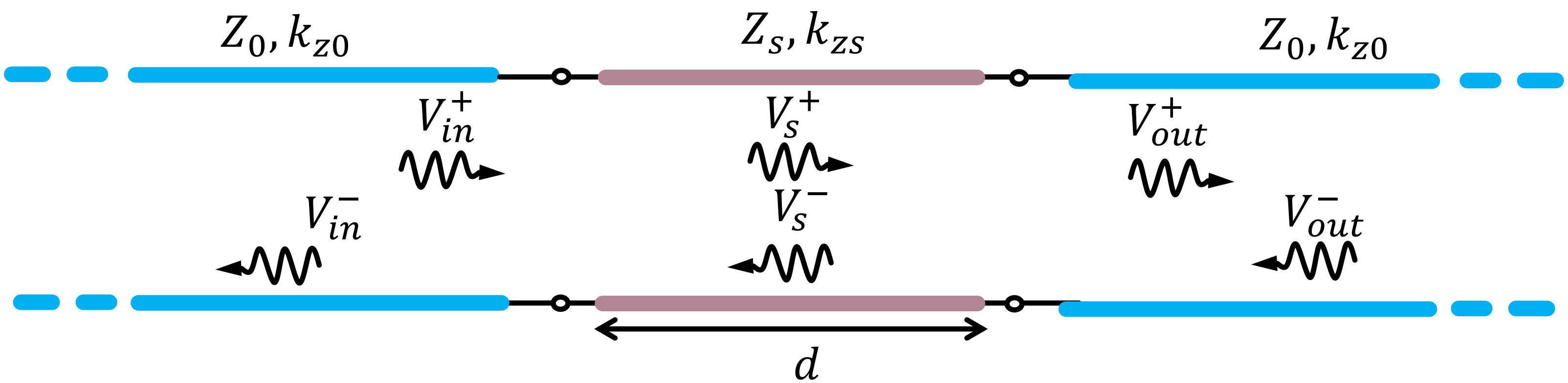
Transmission line model





$$\boxed{\frac{S_{21,sample}}{S_{21,ref}} \sim \frac{V_{\text{out}}^+}{V_{\text{in}}^+}}$$

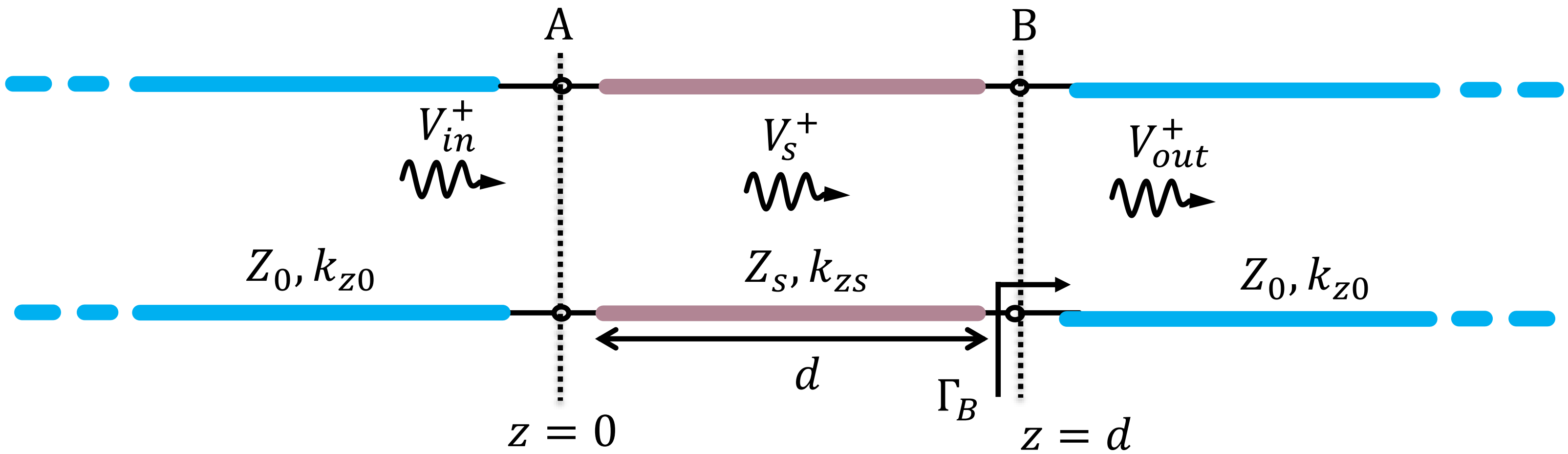
$$Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}},\ Z_d = \sqrt{\frac{\mu_0}{\varepsilon_0 \varepsilon_d}}(1 + j\ tan\delta/2)$$

$$k_{zd} = \beta_d - j\alpha_d$$

$$\beta_d = \omega\sqrt{\mu_0 \varepsilon_r \varepsilon_d}$$

$$\alpha_d = \omega\sqrt{\mu_0 \varepsilon_r \varepsilon_d} tan\delta/2$$

Transmission line model derivation



$$V_s(z) = V_s^+ e^{-jk_{zs}z} + V_s^- e^{jk_{zs}z} = V_s^+[e^{-jk_{zs}z} + \Gamma_B e^{jk_{zs}(z-2d)}]$$

$$V_{out}(z) = V_{out}^+ e^{-jk_{z0}z} \qquad \Gamma_B = \frac{V_s^- e^{jk_{zs}d}}{V_s^+ e^{-jk_{zs}d}} = \frac{Z_0 - Z_s}{Z_0 + Z_s}$$

At boundary B: $V_{out}(z = d) = V_s(z = d)$

$$\frac{V_{out}(z = d)}{V_s(z = d)} = \frac{V_{out}^+ e^{-jk_{z0}d}}{V_s^+ e^{-jk_{zs}d}[1 + \Gamma_B]} = 1 \quad \rightarrow \frac{V_s^+}{V_{\text{out}}^+} = \frac{e^{jk_{zs}d} e^{-jk_{z0}d}}{1 + \Gamma_B}$$

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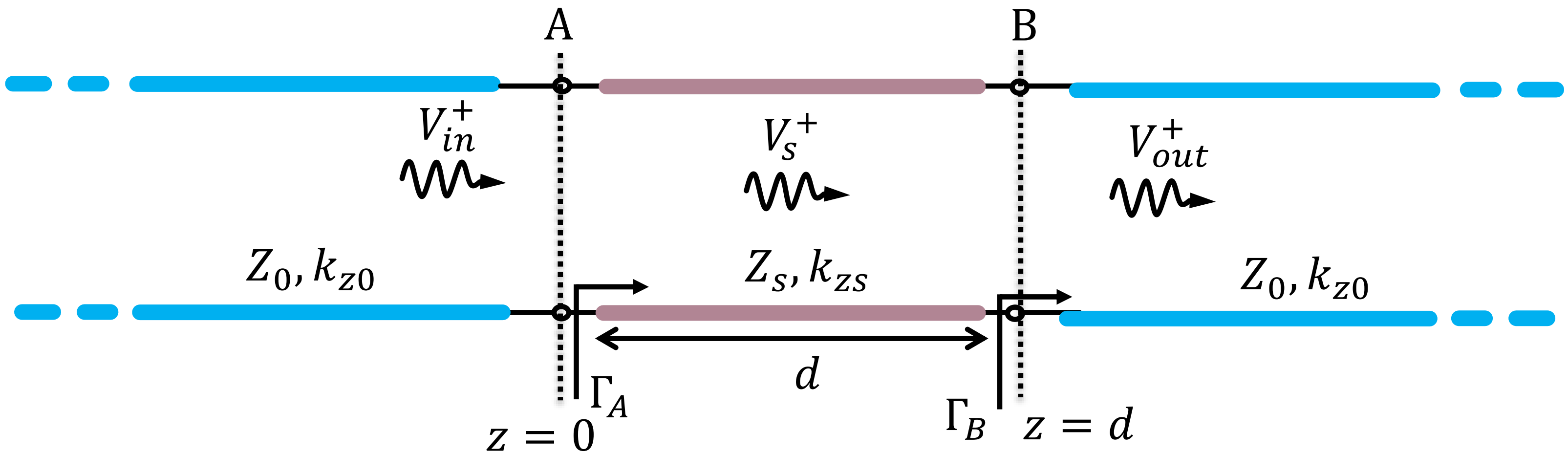
Transmission line model derivation



$$V_s(z) = V_s^{+} e^{-jk_{zs}z} + V_s^{-} e^{jk_{zs}z} = V_s^{+}[e^{-jk_{zs}z} + \Gamma_B e^{jk_{zs}(z-2d)}]$$

$$\Gamma_A = \frac{Z_{in}^A - Z_0}{Z_{in}^A + Z_0}$$

$$V_{in}(z) = V_{in}^{+} e^{-jk_{z0}z}[1 + \Gamma_A]$$

$$Z_{in}^A = Z_s \frac{Z_0 + jZ_s \tan(k_{zs}d)}{Z_s + jZ_0 \tan(k_{zs}d)}$$

At boundary A: $V_{in}(z = 0) = V_s(z = 0)$

$$\frac{V_{in}(z = 0)}{V_s(z = 0)} = \frac{V_{in}^{+}[1 + \Gamma_A]}{V_s^{+}[1 + \Gamma_B e^{-jk_{zs}2d}]} = 1$$

$$\frac{V_{\mathrm{in}}^{+}}{V_{\mathrm{s}}^{+}} = \frac{[1 + \Gamma_B e^{-jk_{zs}2d}]}{[1 + \Gamma_A]}$$

$$\boxed{\frac{V_{in}^{+}}{V_{out}^{+}} = \frac{V_{in}^{+}}{V_s^{+}}\frac{V_s^{+}}{V_{\mathrm{out}}^{+}} = \frac{e^{jk_{zs}d} e^{-jk_{z0}d}}{[1 + \Gamma_B]} \frac{[1 + \Gamma_B e^{-jk_{zs}2d}]}{[1 + \Gamma_A]}}$$